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STRUCTURE OF LARGE AMPLITUDE ABRUPT MAGNETIC VARIATIONS OBSERVED BY THE MAGSAT

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Abstract: The structure and occurrence characteristics of large amplitude abrupt magnetic variations that are frequently observed over the auroral oval are statistically analyzed using the high time resolution data obtained by the MAGSAT. A superposed epoch analysis shows a systematic difference in the structure between the upward and downward field-aligned currents, confirming that the abrupt variations are due to spatial structure of small-scale field-aligned current sheets. The estimated current density is very high ($>90\ \mu A/m^2$). The high density downward currents are canceled by adjacent strong upward currents, and the net current is upward or almost zero. On the other hand, a high density upward current does not necessarily accompany adjacent strong downward current, and the net current around the region is upward. The thickness of the current sheet is normally 0.5–1.0 km or less, suggesting that the events are related to the rayed auroral arc elements. The occurrence frequency decreases rapidly as the amplitude of abrupt jump increases, and the dependence is describable by a simple power function, suggesting that the abrupt jumps are the events that distribute in the high density side trail of the small-scale field-aligned current density distribution.

1. Introduction

The magnetic fields observed by satellites over the auroral oval always contain small scale fluctuations superimposed on large-scale field-aligned current signatures. The small scale fluctuations have been considered to be mainly the signature of small-scale field-aligned currents (*e.g.* SAFLEKOS *et al.*, 1978; IYEMORI *et al.*, 1985), and they often contain large amplitude abrupt variations, for example, jumps in the east-west component greater than 100 nT within 0.06 s (IKEDA *et al.*, 1986). If the large abrupt variations are caused by the satellite crossing of the field-aligned current sheets, as has been suggested by IKEDA *et al.* (1986), the current density must be very high (for example, more than $100\ \mu A/m^2$). The purposes of this study are to confirm that the abrupt variations are attributable to the spatial structure of very high density field-aligned currents and to examine the microstructure and occurrence characteristics of such events.

2. Method of Analysis

The data analyzed in this paper were selected form MAGSAT CRONFIN magnetic tapes that contain high time resolution vector magnetic field data obtained by the MAGSAT. The sampling rate of the magnetometer was 16 s^{-1} and the resolution was 0.5 nT (LANGEL *et al.*, 1981). The data period is from November 2, 1979 through May 17, 1980.

Firstly, we selected the data blocks that contain one or more large abrupt jumps in the geographic east-west component (*By*). The length of one data block is 64 s which contains 1024 data points. The criterion of the event selection is that the variation within 1/16 s in the east-west component is greater than 50 nT. The abrupt jump of 50 nT in *By* within 1/16 s corresponds approximately to the field-aligned current density of 90 $\mu A/m^2$ if stationary sheet current is assumed. The geomagnetic main field and the effect from the large-scale field-aligned currents were subtracted in advance by iterative fitting of parabola for the data in each block.

Using the data base selected as above, the microstructure of the abrupt jumps was analyzed using the superposed epoch analysis. The characteristics of the occurrence frequency were also examined.

3. Results

Figure 1 shows a schematic relationships between the MAGSAT orbit, magnetic field variation and the field-aligned currents viewed from the midnight side. As the MAGSAT was a sun-synchronized satellite, the orbit was approximately on the dawn-dusk meridional plane throughout the MAGSAT lifetime, the ascending node was always on the dusk-side. Therefore, a sudden positive change of the east-west component (*i.e.* eastward variation) corresponds to the satellite crossing of a thin upward field-aligned current on the dawn-side or that of a thin downward field-aligned current on the dusk-side, if we are allowed to assume a quasi-steady sheet current structure.

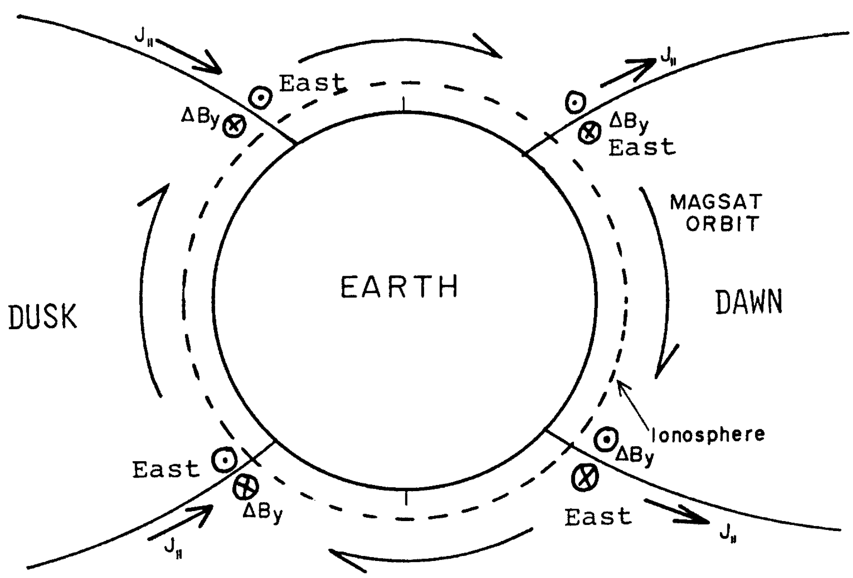

Fig. 1. Schematic explanation of the relationship between the MAGSAT orbit, the direction of magnetic disturbance and the direction of field-aligned currents. A cross-section near the dawn-dusk meridional plane viewed from midnight is shown.

Figure 2 is a result of the superposed epoch analysis. The center of the horizontal axis (*i.e.* the origin of the time axis) is the key time of the superposition when an abrupt jump is observed. The upper and lower two panels were obtained using the data from the dawn sector (*i.e.* between 3 and 9 Magnetic Local Time) and those from the dusk sector (*i.e.* between 15 and 21 MLT), respectively. The positive and the negative jumps were superimposed separately as indicated in the panels. The abrupt variations on the left-side panels correspond to upward currents and that on the right-side panels correspond to downward currents if the abrupt variations are caused by the satellite crossing of quasi-static field-aligned currents. Thick lines indicate the east-west component and thin (and partially broken) lines the north-south component. We can see a characteristic difference in the pattern of the east-west component between the upward current and the downward current.

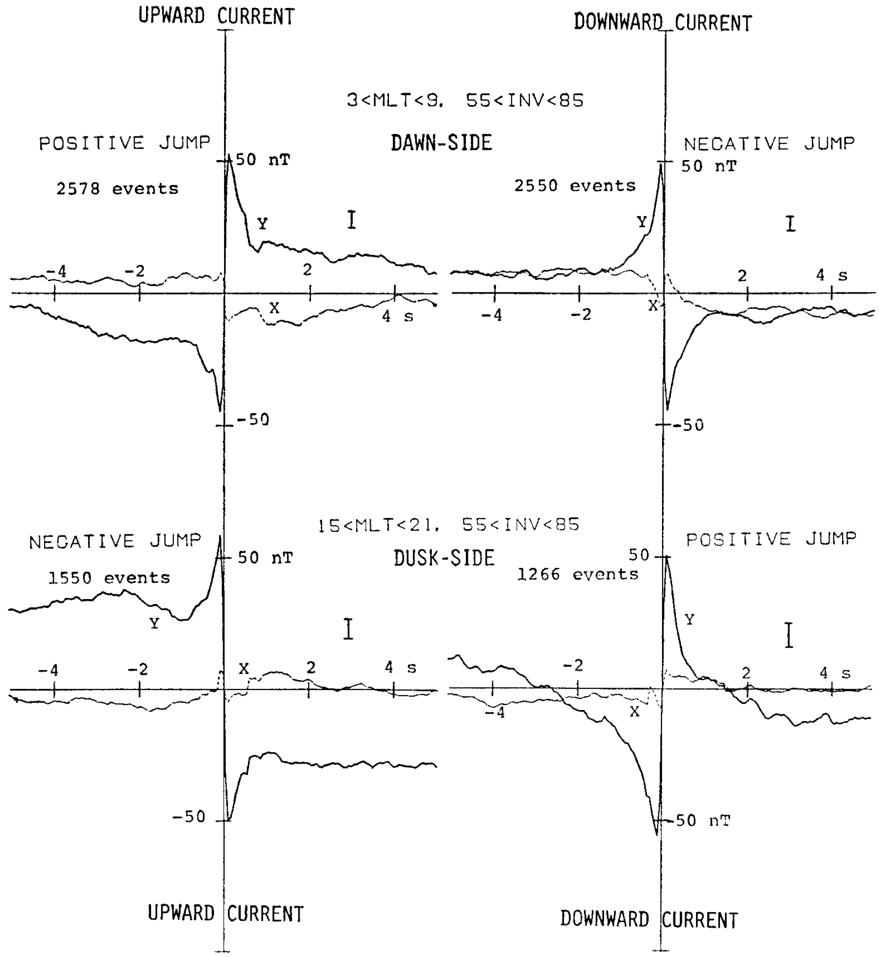

Fig. 2. Superimposed and averaged profiles of the jump events. The origin of horizontal axis corresponds to the time of abrupt jump in the east-west component. Negative and positive jumps in the east-west component are superimposed separately and shown by the thick lines. The thin and partially broken lines denote the profiles of north-south component. The upper two panels are the profiles of the positive and the negative jumps on the dawn-side that correspond to the upward and the downward currents, respectively. The lower two panels are the results on the dusk-side that show a clear difference in the pattern between the upward and downward currents.

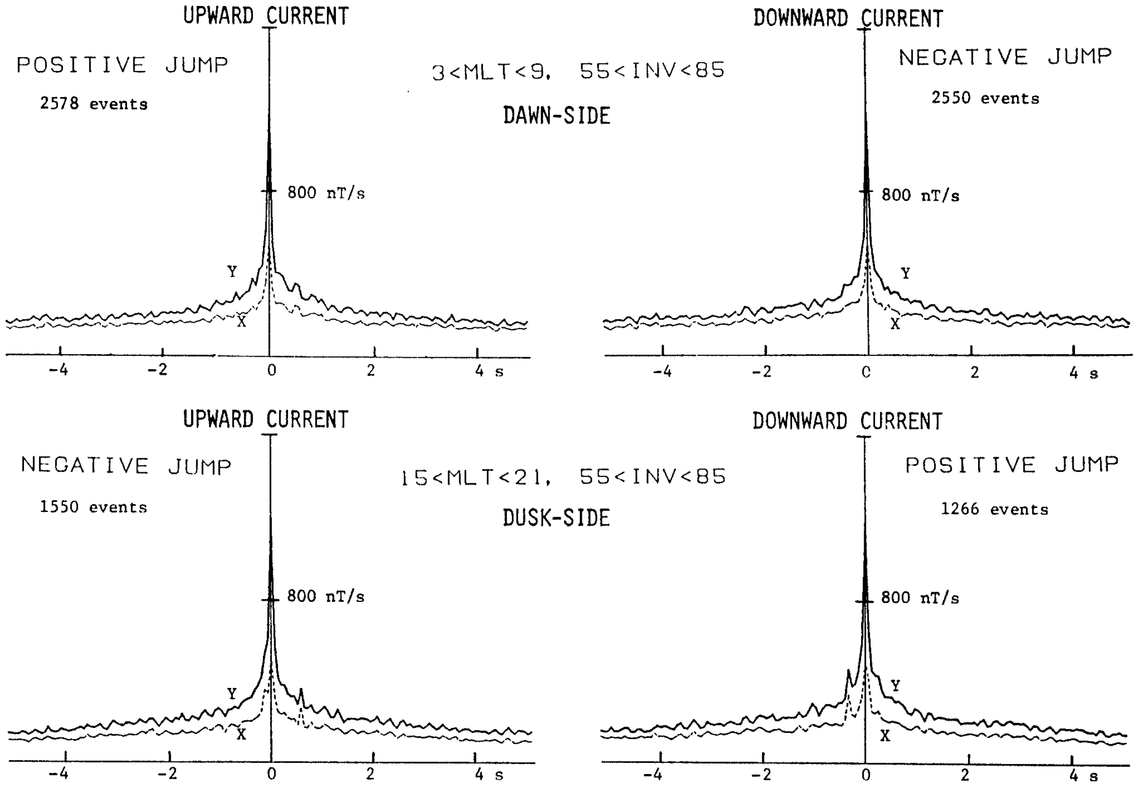

Fig. 3. Averaged profiles of the time change rate of the jump events. The same data base with that in Fig. 2 was used. Both the X- (i.e. thin and broken lines) and Y- (i.e. thick lines) components have the maximum change rate at the origin of the time axis.

Figure 3 shows the averaged profiles of the absolute value of the time change rate. The data base is the same with that of Fig. 2. The time change rate shows its maximum for both X- and Y-components at the origin of the axis, indicating that the sheet-type current structure is a better approximation than a line-type current structure, because the latter model requires a minimum change rate for the X-component at the origin, where the Y-component shows a maximum change rate.

Figure 4 upper panels and lower panels were obtained from the data in the northern dusk sector and the southern dusk sector, respectively. The profiles are essentially the same for both the northern and the southern hemispheres, indicating that a systematic movement of the current sheet in the north-south direction is not the cause of the characteristic differences between the upward and downward currents, because the satellite motion is opposite in the north-south direction between both hemispheres.

The apparently "upward" thin current sheets with the thickness of 0.5–1.0 km carry most of the net "upward" currents over the horizontal scale of 20–50 km (corresponding to 2–4 s in the abscissa of Figs. 2 and 4) at the MAGSAT altitude, which is seen as the sudden shift of the level of mean By value across the jump in Figs. 2 and 4. On the other hand, the profiles of the apparent "downward" currents indicate almost no net current or, on the contrary, they indicate the existence of a net "upward" current in the horizontal scale of 20–50 km, because the shift of the mean By level across the jump is nearly zero or, especially on the dusk-side, opposite direction to the abrupt

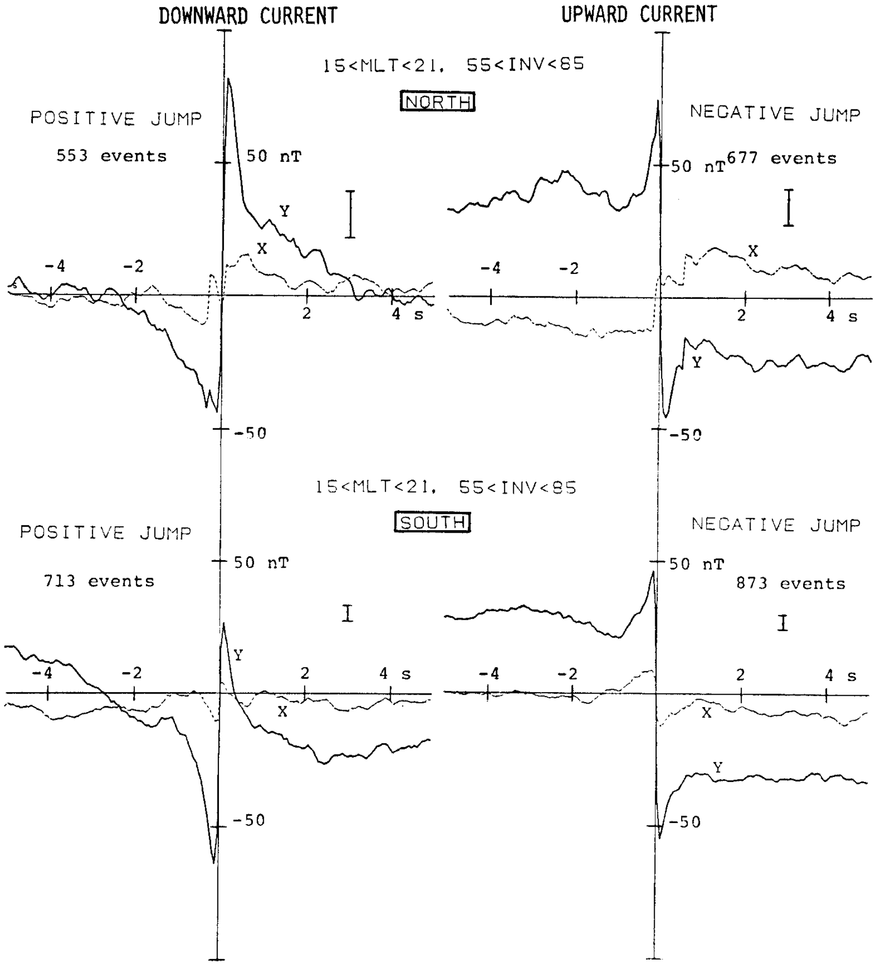

Fig. 4. The events observed in the auroral zone of the northern and the southern hemispheres are superimposed separately. The upper two panels and the lower two panels correspond to the northern dusk sector and the southern dusk sector, respectivly. The profiles for these two regions are essentially the same.

jump. This systematic difference between the apparent "upward" and "downward" currents justifies the assumption that the abrupt jump events are the indication of the satellite crossing of quasi-static field-aligned sheet currents. In both "upward" and "downward" events, the "jump" occurs almost within 1/16 s which correspond to the spatial distance of about 500 m. Adjacent to the very high current density region which corresponds to the abrupt jump, the oppositely directed currents flow on both sides. This signature can be seen both in the "upward" and "downward" events as the "overshoot" of the jump.

The upper panels of Fig. 5 were obtained from the data on the higher latitude side of the auroral oval (*i.e.* invariant latitude between 70° and 80°), while the lower panels were from the lower latitude side of the auroral oval, both on the dusk-side. The characteristics of the variations are essentially the same with those in Fig. 2 for both the upper and lower panels. As the demarcation line between the large scale field-aligned current region-1 and -2 (*e.g.* IIJIMA and POTEMRA, 1978) is statistically around 70° invariant latitude, the essentially same profiles in both regions indicate that the char-

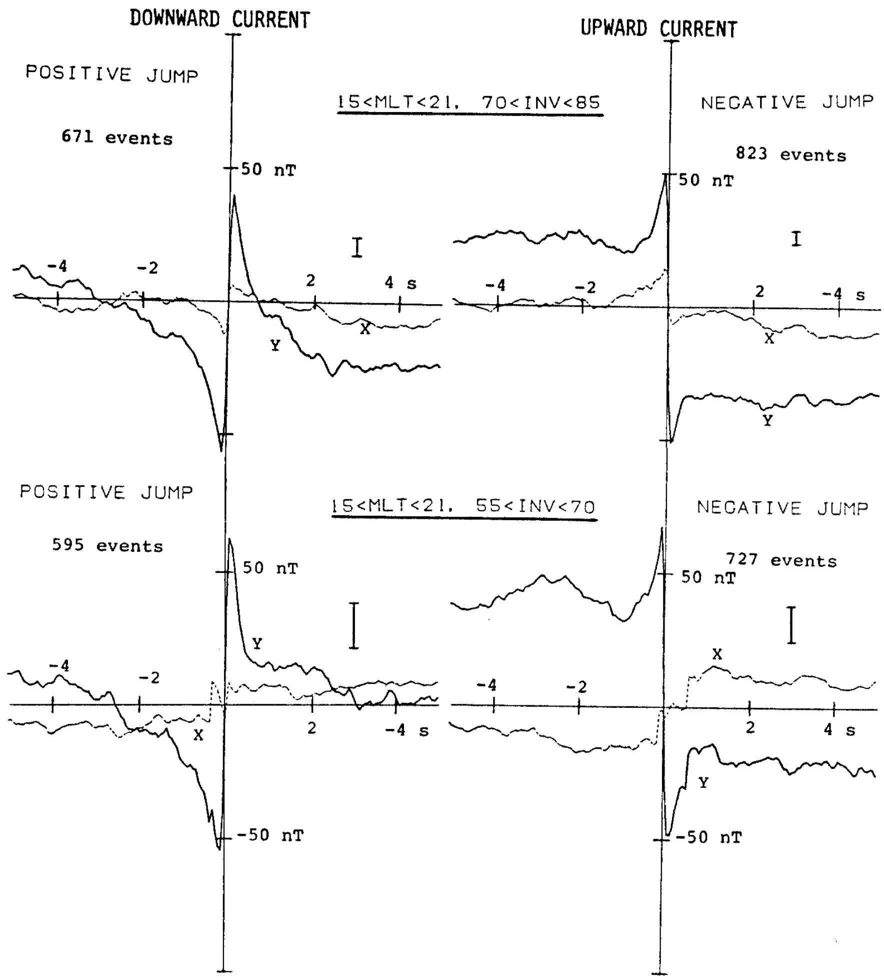

Fig. 5. The events observed on the higher latitude side (70° < Inv. Lat. < 85°) and the lower latitude side (55° < Inv. Lat. < 70°) of the auroral zone are superimposed separately. The upper two panels and the lower two panels correspond to the higher latitude zone (i.e. near the field-aligned current region-1) and the lower latitude zone (i.e. near the field-aligned current region-2), respectively. The profiles for these two regions are essentially the same.

acteristics of the events in region-1 are not different from those in region-2.

Figure 6 shows the amplitude dependence of the occurrence frequency of the events. The number of the events detected throughout the MAGSAT lifetime rapidly decreases as the amplitude increases. The amplitude and the number of the detection have a linear relationship in a logarithmic scale. That is, the number of events is proportional to the amplitude to the power -3.7. The dotted line is a linear extrapolation of the relationship in the large-amplitude region to the small-amplitude side. If the extrapolation is valid, all the data period when the MAGSAT was in the polar region is covered by the jump with the amplitude about 5 nT. That is, the estimated number of event times the sampling interval (*i.e.* 1/16 s) roughly equals to the period that the MAGSAT was in the polar region ($\sim$60 days), and this amplitude is comparable to the amplitude of persistent small scale magnetic fluctuations over the auroral oval obtained by Iyemori *et al.* (1985).

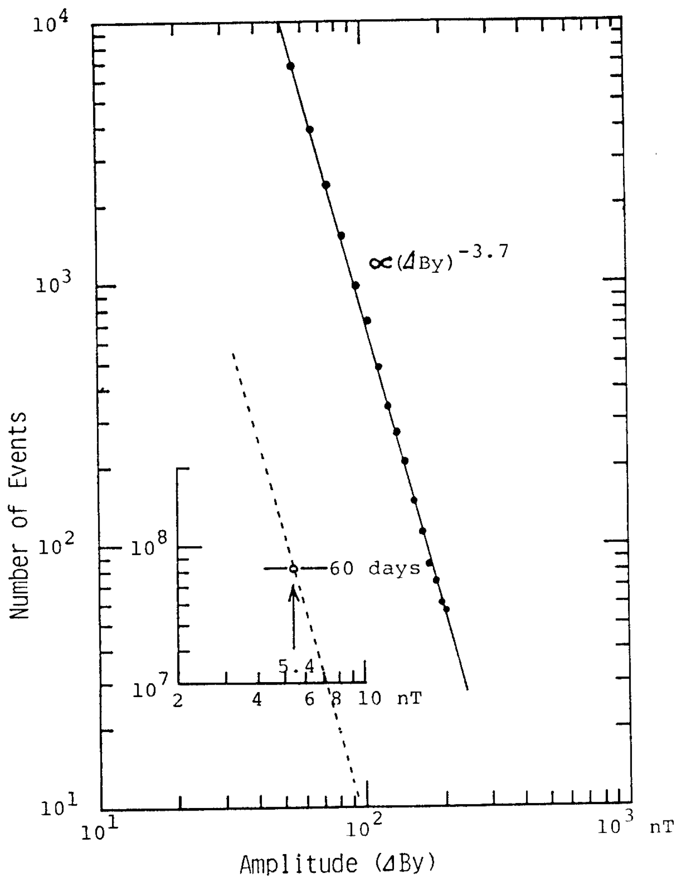

Fig. 6. The amplitude dependence of the frequency of the encounter with the jump events. The number of events with the amplitude greater than 50 nT in 1/16 s were counted. The dotted line is a linear extrapolation to the small-amplitude side. If the linear relationship between them in a logarithmic scale holds also in the extrapolated region, the total period of MAGSAT lifetime over high latitudes (i.e. about 60 days) is covered by the jump with the amplitude about 5.4 nT which is in the same order of magnitude with the average amplitude (i.e. standard deviation) of small scale fluctuations over the auroral zone.

4. Discussion

The most significant result of this study is the systematic difference in the pattern of superimposed profiles of the abrupt variations between the cases of apparent "upward" and "downward" currents. This fact justifies or confirms the assumption that most of the abrupt jumps observed are due to spatial structure of very high density field-aligned current sheets, as has been suggested using the same data base but from somewhat different point of view by IKEDA *et al.* (1986). If the abrupt jumps are caused by a rapid movement of the current sheet with a faster speed than the satellite velocity, such systematic difference may not appear. Hence the speed of the current sheet displacement must be, at least statistically, less than the satellite velocity (*i.e.* <8 km/s). Therefore, the error in the estimation of the maximum thickness or the minimum density of the current sheet under the assumption of a stationary sheet current is within a factor of 2.

The superimposed profiles indicate that the very high density downward current sheets with a thickness of about 500 m or less exist in the net upward current region of 20–50 km latitudinal scale. On the other hand, the region which contains a very high density upward current is also the region of net upward current and the net current concentrates in a narrow region. In other words, a very high density upward current can flow without adjacent strong downward currents, but a very high density downward curent cannot flow without adjacent strong upward currents. As the field-aligned currents are carried mainly by precipitating electrons from the magnetosphere (*i.e.* upward current) or by thermal electrons accelerated upward from the ionosphere (*i.e.* downward current), the existence of a net upward current around strong downward currents suggests that the potential structure which accelerate the ionospheric electrons upward is formed in the net upward current region of 20–50 km scale.

The thickness of the current sheet is normally less than 0.5–1.0 km which is very thin compared with the potential structure observed as an inverted V which has the horizontal scale about 100 km (*e.g.* LYONS and WILLIAMS, 1984). The thickness of an auroral arc element is said to be the order of 1 km or less. Therefore we may be looking the magnetic signature of the field-aligned currents associated with the rayed auroral arc elements.

The spatial resolution of the MAGSAT observation is about 500 m. On the other hand, the median thickness of the auroral arc elements is reported to be 230 m by MAGGS and DAVIS (1968). Hence we can expect more fine structure in the abrupt magnetic jump events examined in this paper. The sounding rocket experiments of magnetic field measurements have shown much complexity of smaller spatial scale than that of the MAGSAT (*e.g.* LEDLEY and FARTHING, 1974). Therefore the examination of the rocket data may be useful for further investigation of abrupt jump events.

The approximate agreement in magnitude between the extrapolated amplitude of 5 nT shown in Fig. 5 as an fluctuation of each data point and the standard deviation of small scale fluctuations obtained by IYEMORI *et al.* (1985) suggest that the large amplitude abrupt jumps are the events that distribute in the high density side trail of the small scale field-aligned current density distribution. In other wards, the large scale field-aligned current region, where the strong magnetosphere-ionosphere coupling occurs, is covered by the small-scale field-aligned currents with the scale size less than 0.5–1.0 km (*e.g.* SUGIURA *et al.*, 1984).

High resolution DC electric and magnetic field observation by a low-altitude satellite with fine time resolution, for example, 50 samples/s, is called for to clarify the relationships among the large-scale field-aligned current, small-scale field-aligned current, the very high density field-aligned current and the fine structure observed by rocket experiments.

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